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3D Studies of Neutral and Ionised Gas and Stars in Seyfert and Inactive Galaxies

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Abstract

We are conducting the first systematic 3D spectroscopic imaging survey to quantify the properties of the atomic gas (HI) in a distance-limited sample of 28 Seyfert galaxies and a sample of 28 inactive control galaxies with well-matched optical properties (the **VHIKINGS** survey). This study aims to address the role of the host galaxy in nuclear activity and confront outstanding controversies in optical/IR imaging surveys. Early results show possible relationships between Seyfert activity and HI extent, content and the prevalence of small, nearby gas-rich dwarf galaxies ($M_{\text{HI}} \sim 10^7 M_{\odot}$); results will be tested via rigorous comparison with control galaxies. Initial results from our optical followup study of 15 of our galaxies using the SAURON integral field unit on the WHT suggest a possible difference between Seyfert and inactive stellar and gaseous kinematics that support the conclusion that internal kinematics of galaxies are the key to nuclear activity.

Key words: galaxies: Seyfert — galaxies: kinematics and dynamics

1 Introduction

Traditionally, the broader study of the formation, structure and evolution of galaxies largely excluded Active Galactic Nuclei (AGN: distant quasars and nearby Seyfert galaxies), whose energy output is primarily powered by the release of gravitational potential energy as material from the host galaxy is accreted by a central supermassive black hole. Recently, however, it has been recognised that the growth and influence of the black hole, the formation/evolution of galaxies, star formation and nuclear activity at different cosmic epochs are intimately related (e.g. 1; 2; 3), and that most bulge-dominated galaxies today harbor relic black holes from an early quasar phase (e.g. 4; 5).

Local galaxies are well-established, so re-ignition of dormant black holes is required to explain why ongoing activity is observed in only 10–20% of galaxies, despite the ubiquity of black holes. A key question is whether the ignition mechanism is related to the galactic host properties; numerical models predict large gas inflows due to gravitational torques in non-axisymmetric potentials related to bars or galaxy interactions (6; 7; 8), but the majority of optical/IR *imaging* studies have failed to find a clear distinction between Seyfert host and inactive galaxy morphology on a range of scales that encompasses nearby companions and interactions, galactic bars and nuclear spirals (e.g. 9; 10; 11). However, recent NICMOS imaging of the circumnuclear regions of 250 galaxies (12) found significant isophotal twists and disturbances suggesting the possibility of identifiable *dynamical* differences between active and inactive hosts.

Removal of angular momentum and transportation of disk gas towards the nucleus may be driven by external mechanisms, such as tidal interaction or minor mergers, or internal instabilities such as bars and lopsided disks. HI is often the most spatially extended component of a galaxy’s disk so is sensitive to interactions and minor mergers; because gas is dissipative, it also responds in a highly non-linear way to small deviations from axial symmetry making it a valuable tracer of barred or weak oval potentials (13). HI synthesis imaging provides unique information on the global mass distribution and kinematics of the disk to large radii and a long-term dynamical history of the galaxy; interactions and mergers alter disk gas masses, bars drive gas inwards and even small disturbances leave *kinematic* imprints.

Ionised gas kinematics trace the gaseous response closer to the nucleus, while stellar (ballistic) dynamics provide independent constraints on the potential in the presence of strong gaseous streaming. Here we describe 3D studies of the distribution and kinematics of neutral and ionised gas and stars in active and inactive galaxies.

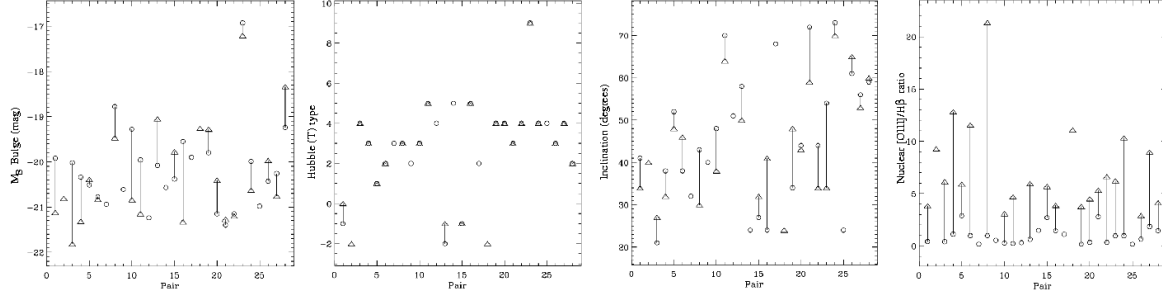


Fig. 1. Bulge magnitude (M_B), Hubble type (T), inclination (i) and nuclear $[\text{OIII}]/\text{H}\beta$ ratio for the VHIKINGS sample Seyfert (Δ) and control (\circ) pairs.

2 The VLA Hydrogen Imaging and Kinematics of Inactive Galaxies and Seyferts Survey (The VHIKINGS Survey)

The VHIKINGS survey is a high angular resolution ($20''$) HI synthesis imaging spectroscopic survey of 56 Seyferts and inactive controls which aims to compare statistically the structural and dynamical properties of active and inactive galaxies, specifically (a) relationships between the presence of nuclear activity and disk properties such as HI content, distribution, global and detailed kinematics; (b) the gaseous environment of active and inactive galaxies, such as the prevalence of gas-rich low optical brightness dwarf galaxies.

Our master sample is selected from the RSA catalogue with complete nuclear spectroscopic classification (14) and comprises 39 Seyfert galaxies, with $V_{\text{sys}} < 4000 \text{ km s}^{-1}$, $B_T < 12.5 \text{ mag}$, $20^\circ < i < 70^\circ$, paired with 39 control galaxies with carefully matched optical properties B , V , i and Hubble type, T (RC3 classification plus visual confirmation of DSS images). For the VHIKINGS survey, the brightest 26 Seyferts (absolute nuclear V-band magnitudes < -17.2) and their corresponding 26 control galaxies were selected from this master sample (Table 1), plus fainter Seyferts, M51 and M81 and their controls. Figure 1 shows a pair-wise comparison of some sample properties.

The VHIKINGS survey is motivated by single dish HI surveys of Seyferts, which found $\sim 40\%$ of Seyferts (15; 16) showed disturbed kinematic profiles different to those of normal galaxies and a larger scatter in the distributions of M_H/L_B and M_H/M_D ratios vs. Hubble type, and detailed VLA HI studies of individual Seyfert hosts, which revealed tidal tails and intra-group gas (17; 18; 19), previously unknown dwarf galaxies close to, but distinct from main disks (17) and non-linear gas dynamics, such as streaming shocks in bars (13).

The VLA in C-configuration was used with an instrumental setup that ensures sensitivity to column densities $N_H > 10^{20} \text{ cm}^{-2}$ and a bandwidth corresponding to $\Delta V = 1100 \text{ km s}^{-1}$; this combination is proving valuable for accurate continuum subtraction and the detection of gas-rich dwarf galaxies with low

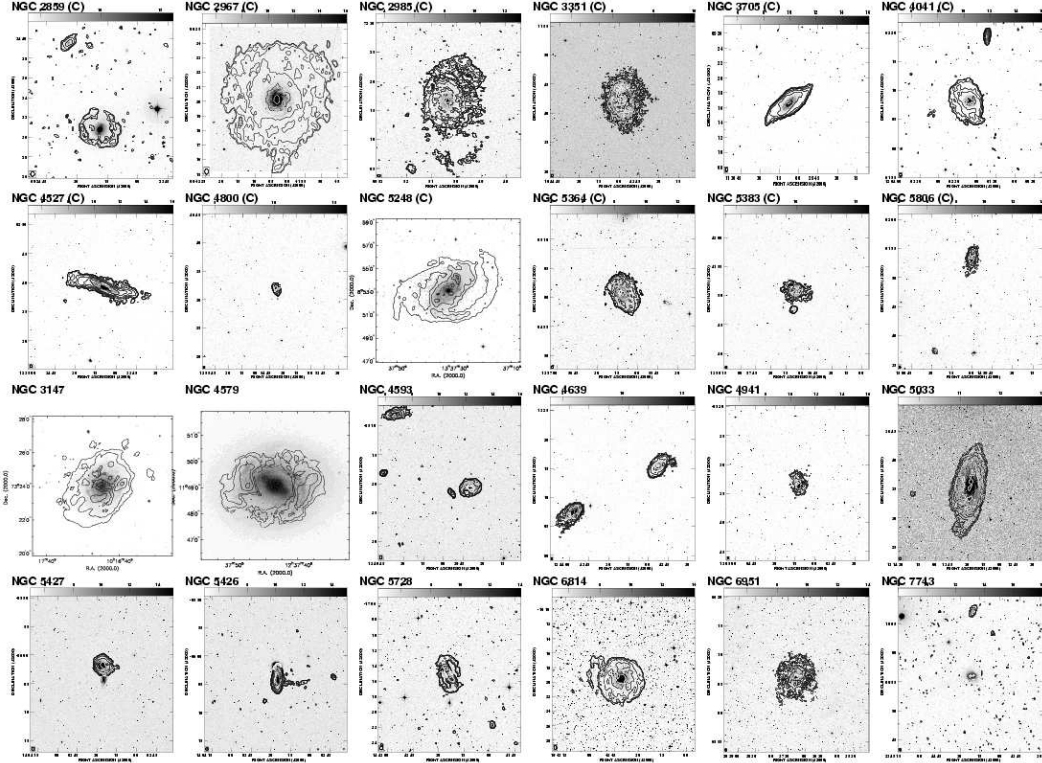


Fig. 2. VLA HI images of a selection of galaxies from the VHIKINGS survey (HI intensity contoured on DSS R-band images).

optical surface brightness that are in the field of view and within the velocity range to be associated with the target galaxies. These satellites are often absent from archive data that fail to cover a sufficient velocity range. Some of these satellites can be seen in Figure 2, which shows a selection of HI maps of Seyferts and controls (C) from the survey. Wider comparisons with galaxies in the WHISP survey (20) is underway.

3 Complementary Optical IFU Followup Studies

We have used the SAURON IFU on the WHT to conduct a 3D imaging spectroscopic study of stellar and gaseous distributions and kinematics of the central kiloparsecs of a distance-limited ($V_{sys} < 1600 \text{ km s}^{-1}$) subsample of active and inactive galaxies selected from the VHIKINGS sample (Dumas et al. in preparation). This study was motivated by the clear inadequacy of single aperture spectra or long-slit data or imaging alone in the presence of complex host and nuclear kinematics. The data form part of a multiwavelength campaign to investigate host galaxy structure and kinematics on size scales ever-closer to the nucleus, aimed at identifying or eliminating possible AGN triggering and fuelling mechanisms (see also García-Burillo these proceedings). This work

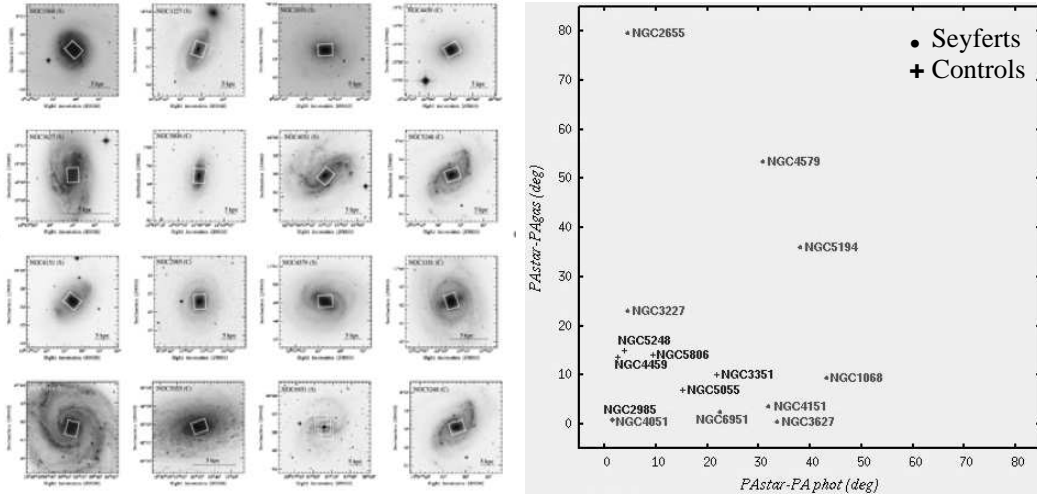


Fig. 3. DSS R-band images of SAURON subsample, where \square = observed regions; Comparison of differences in mean position angle of photometric (phot) and kinematic (stars and gas) axes, $PA(phot - stars)$ vs $PA(stars - gas)$.

builds on our previous detailed studies of 2-D gaseous and stellar velocity fields of individual Seyfert galaxies, such as NGC 4151 (13; 21), NGC 2110 (22) and NGC 1068 (23) where evidence of gaseous streaming and inflow in the inner few kpc was identified, hinting at a mechanism for delivering gas to the circumnuclear regions. Fig. 3 shows DSS images of the SAURON subsample (Left panel) and a comparison of photometric and kinematic axes position angles. Comparisons are also being made with a wider range of Hubble types from the SAURON survey of early type galaxies (25; 24; 26) and LINERs in elliptical hosts from Peletier & Barthel (in prep.). Detailed modelling of the 2D stellar and gaseous kinematics is underway to identify and quantify deviations from circular motion that may be important for nuclear fuelling, using both tilted ring modelling and Fourier decomposition (e.g. 27; 28; 23) (see also Peletier these proceedings).

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